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NORTHROP CORPORATE LABORATORIES

CO_2 LASER PULSING TECHNIQUES
ANNUAL REPORT
SEPTEMBER 1970

Prepared by
Electromagnetics Laboratory
Northrop Corporate Laboratories

Office of Naval Research
Contract No. N00014-70-C-0185
December 1969 to December 1971

Sponsored by
Advanced Research Projects Agency
Order No. 306

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Principal Investigator: Dr. M. L. Bhaumik
Tel: AC 213 675-4611

Project Scientist: Dr. M. M. Mann
Tel: AC 213 675-4611

NORTHROP CORPORATE LABORATORIES
3401 West Broadway
Hawthorne, California 90250

NOTICE

SUMMARY

This is the first annual report by research performed under Office of Naval Research Contract No. N00014-70-C-0185, sponsored by the Advanced Research Projects Agency. The work was performed by the Laser Group of the Electromagnetics Laboratory, Northrop Corporate Laboratories. The Principal Investigator of the program is Dr. M. L. Bhaumik and the Project Scientist is Dr. M. M. Mann. Other contributors to the program include: Dr. W. B. Lacina, Mr. R. G. Eguchi and Dr. W. H. Steier.

The objective of this program is to investigate and develop CO_2 laser pulsing techniques. The current effort is directed at developing techniques for producing stable pulse trains from the CO_2 laser. This technology is requisite to applications of the CO_2 laser in communications and ranging. One of the attractive methods of obtaining a repetitively pulsed output is by mode locking.

During the period covered by this report, the experimental facility was constructed and experimental investigation of active and passive electro-optic mode locking was initiated. Continuous mode locking of a CO_2 laser has been obtained with the use of an internal electro-optic phase modulator driven at the axial mode difference frequency. Pulses of less than 25 nanosecond duration and 147 nanosecond period

(6.8 MHz repetition rate) were observed using a folded resonator configuration 22 meters in length. Stable locking was obtained with an r.f. input power to the modulator of approximately one milliwatt. By comparison, previous approaches to mode locking the CO_2 laser have employed loss modulation or non-linear interaction in the gain medium of a Q-switched laser requiring very large modulator powers. The pulsing technique developed in the present program has the important advantage of enhanced long term stability obtained by coupling the laser to an external low power frequency standard.

The experimental method and results of mode locking of the CO_2 laser by intracavity phase modulation are presented in detail in the rest of this report. These results represent the major accomplishment of this contractual effort to date. Analytical and experimental efforts are underway to develop a high power, short cavity, mode locked laser for practical systems.

ABSTRACT

In a study of CO_2 Laser Pulsing Techniques, sponsored by the Advanced Research Project Agency, under Office of Naval Research Contract N00014-70-C-0185, stable mode locking of a CO_2 laser has been achieved with the use of a resonated internal electro-optic phase modulator driven at frequencies near the axial mode interval. Pulses of 25 nanosecond duration and 147 nanosecond period were observed. Pulse trains at twice the fundamental mode frequency were also obtained. Stable locking was achieved with an r.f. input power to the modulator of less than 1 milliwatt. Locking could be induced when the modulation frequency was within ± 130 kHz of the fundamental axial mode frequency.

MODE LOCKING OF THE CO_2 LASER BY INTRACAVITY PHASE MODULATION

Previous approaches to mode locking of the CO_2 laser have depended on loss modulation[1, 2, 3] or non-linear interaction in the gain medium.[4, 5] In experiments reported here, mode locking was obtained with the use of an intracavity electro-optic phase modulator driven at frequencies near the axial mode interval. Drive requirements were minimized and locking stability enhanced by resonating the modulator crystal at the drive frequency.

The laser configuration employed in these experiments consisted of a 40 mm i.d. x 6 meter discharge tube and a 22 meter folded optical resonator with four folds providing an axial mode separation of 6.8 MHz (Figure 1). All components were mounted on massive granite supports to provide mechanical stability. The resonator configuration and mirror focal lengths were chosen with the aid of a computer resonator design program to simultaneously satisfy the requirements for a large mode volume in the discharge region and a small beam diameter (~ 1 mm) at the output end of the resonator where the modulator element was located. A variable aperture was included in the cavity to provide transverse mode selection. A slow speed chopper was interposed in the optical path to limit the duty cycle to approximately 0.5% in order to minimize the possibility of thermal damage to the modulator element or output mirror. The aperture time was sufficiently great (200 microseconds to 300 milliseconds) to insure that conditions were characteristic of CW operation. The laser output was monitored via a 2% transmitting output mirror with a liquid helium cooled Ge:Cu detector.

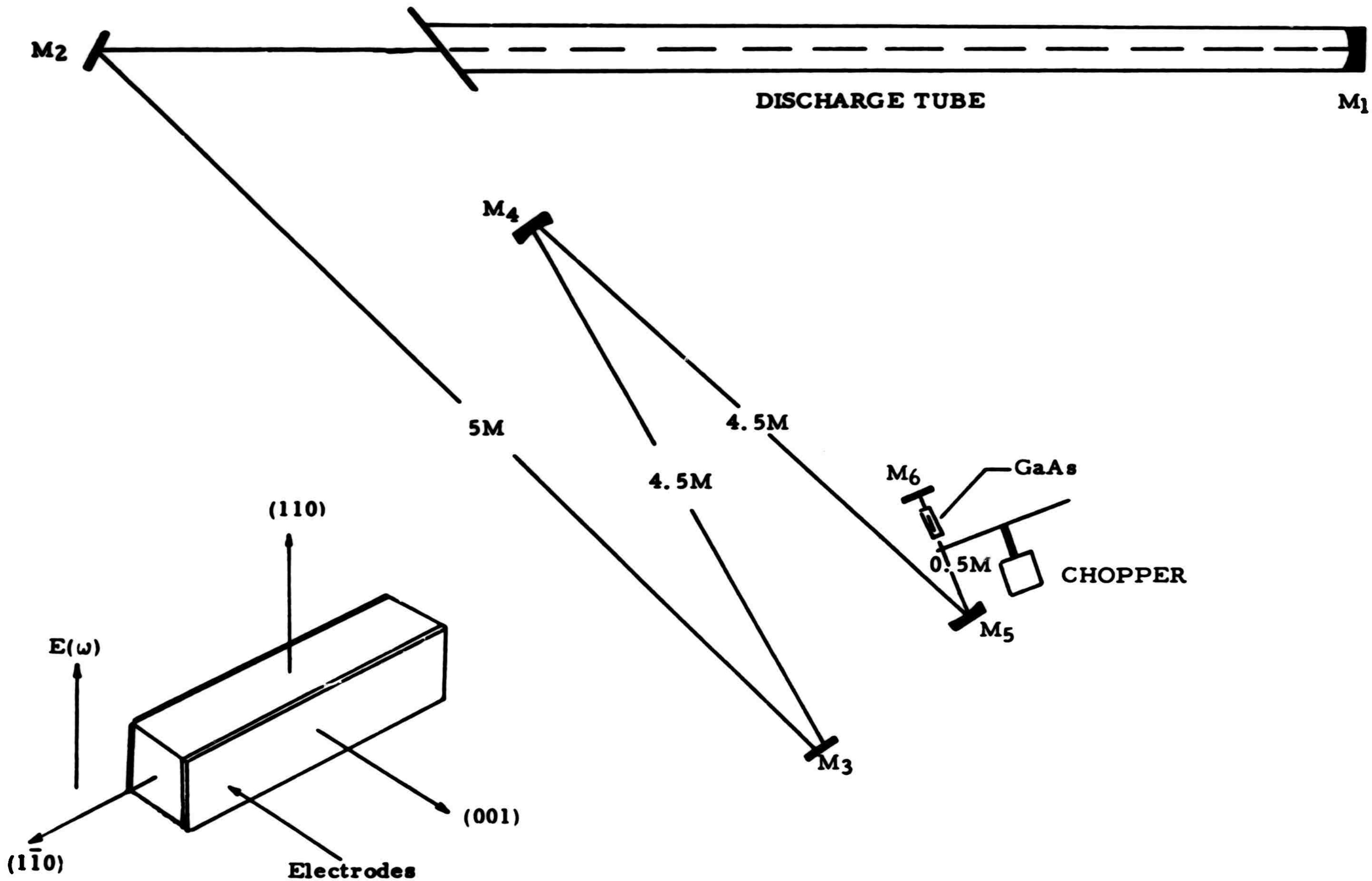

Figure 1 Resonator Configuration: Mirror Radii M_1 - 20 M, M_2 - Flat, M_3 - Flat, M_4 - 10M, M_5 - 1M, M_6 - Flat. Inset: GaAs orientation.

A high resistivity gallium arsenide crystal, 3 x 3 x 50 mm, with electrodes deposited on the (001) faces was used as the phase modulator. The optical field was polarized along the (110) direction by a sodium chloride Brewster window on the discharge tube. The crystal was resonated in a high Q (~ 300) parallel LC circuit at a frequency corresponding to the drive frequency. The modulator resonator was inductively coupled to a tunable r.f. driver.

Under typical operating conditions a 10 torr mixture of CO_2(4.5%): N_2(12.0%):He(83.5%) was used. The discharge current was 20 ma.

With the r.f. driver tuned to the fundamental axial mode frequency, stable locking could be obtained with a signal as small as 0.5 volts peak to peak from the modulator driver. This corresponds to a modulator drive power of 1 milliwatt. Under these conditions, pulses with Gaussian profiles 40 nanoseconds wide and 147 nanosecond period were observed (Figure 2). Increasing the signal to 10V peak to peak decreased the pulse duration to 25 nanoseconds (Figure 3). Further increases in the applied voltage produced a gradual sharpening of the pulse form, but quantitative measurements were hampered by the bandwidth limitations of the detection electronics. The ratio of peak mode locked pulse power to cw power was 4.5 to 5.5. The average power in the locked mode of operation was 94% of the cw power. These results are consistent with the observations of the radio frequency spectral characteristics of the detector output which indicated that 5 to 6 modes were locked.

Measurements were made of the phase of the pulses with respect to the modulator drive signal. It was found, in agreement with theory,[6,7] that the pulses traversed the crystal at either (or both) extremum(a) of

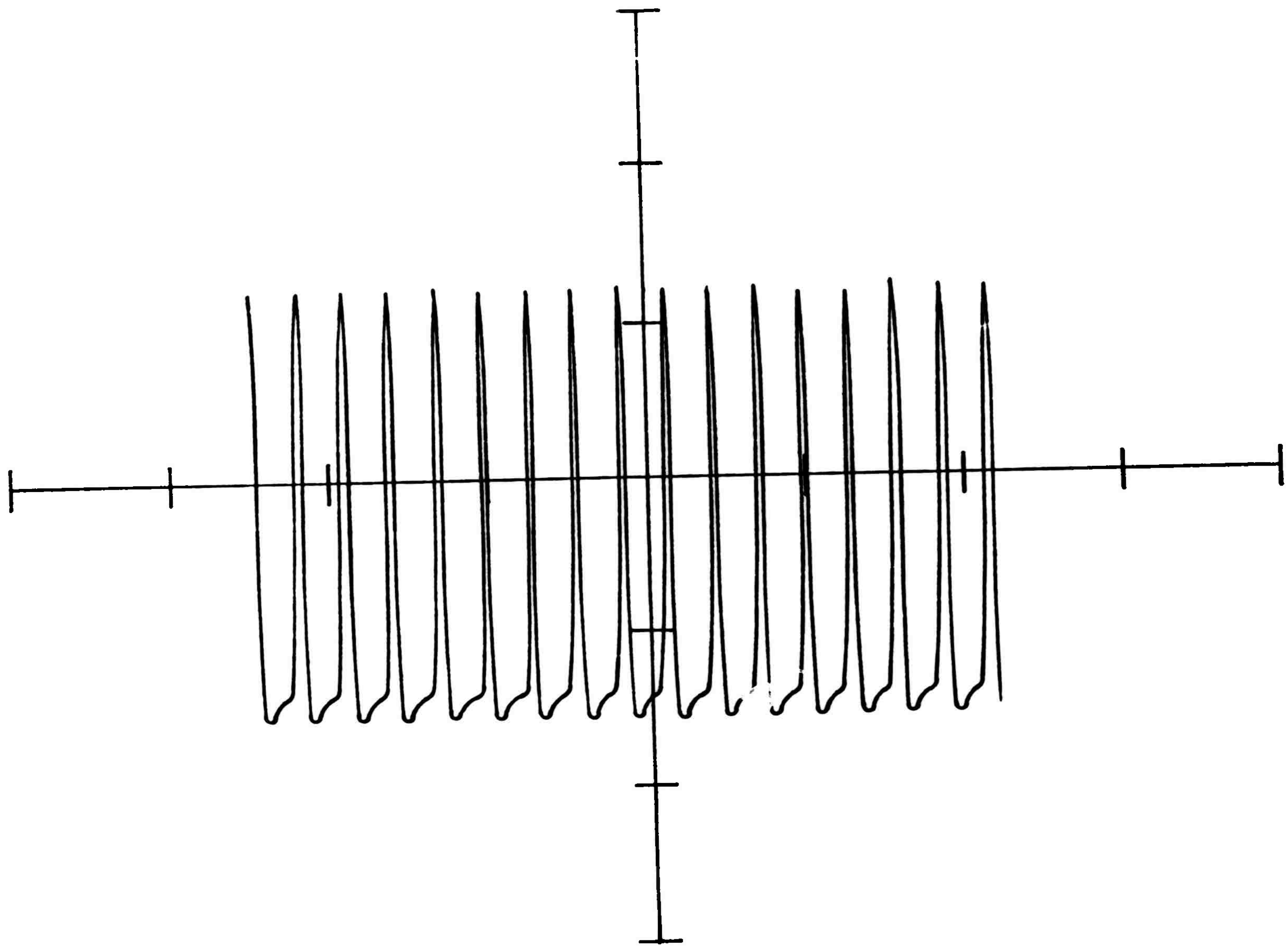

Figure 2 Mode locked pulse train. Time scale - 500 ns/div.

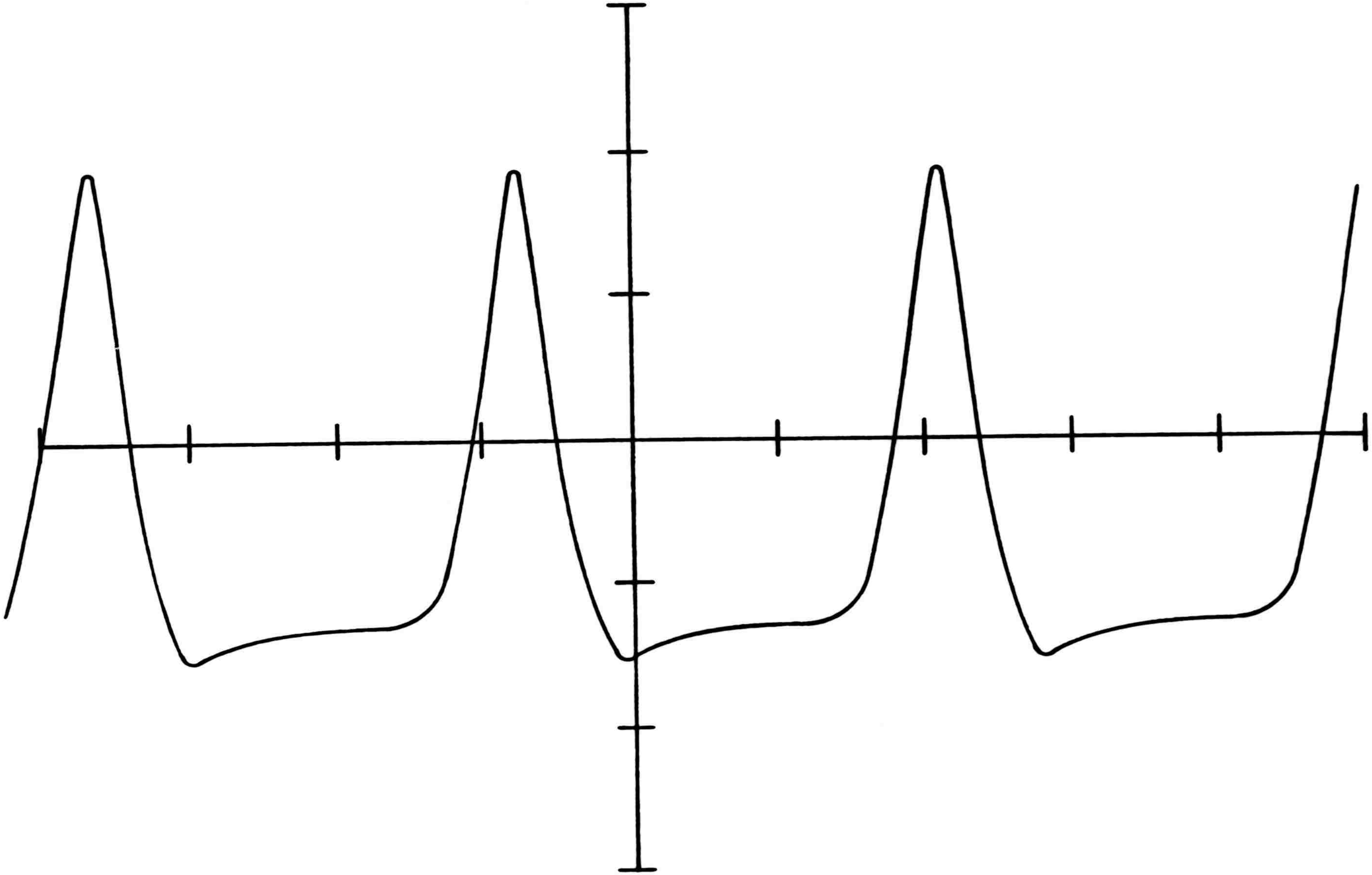

Figure 3 Mode locked pulses with 10V drive. Time scale - 50 ns/div.

of the phase perturbation, depending on the critical positioning of the output mirror. The three cases are illustrated in Figure 4. In each instance the upper trace is the drive signal and the lower trace is the laser output. In these figures all extraneous delays have been compensated, and the modulator driver was tuned to the axial mode interval. The repetition rate of the pulse train in the lower figure is equal to twice the fundamental mode frequency. These results are in agreement with the previously reported investigation of mode-locking in He-Ne lasers.[8]

Locking could be induced when the modulation frequency was within ± 130 kHz of the fundamental axial mode frequency of 6.8 MHz. In each case the modulator resonator was tuned to the drive frequency. The drive voltage required to obtain locking at the extremes of the tuning range was approximately 20 times as great as that required when the driver was tuned to the mode interval, and the pulse form was significantly degraded.

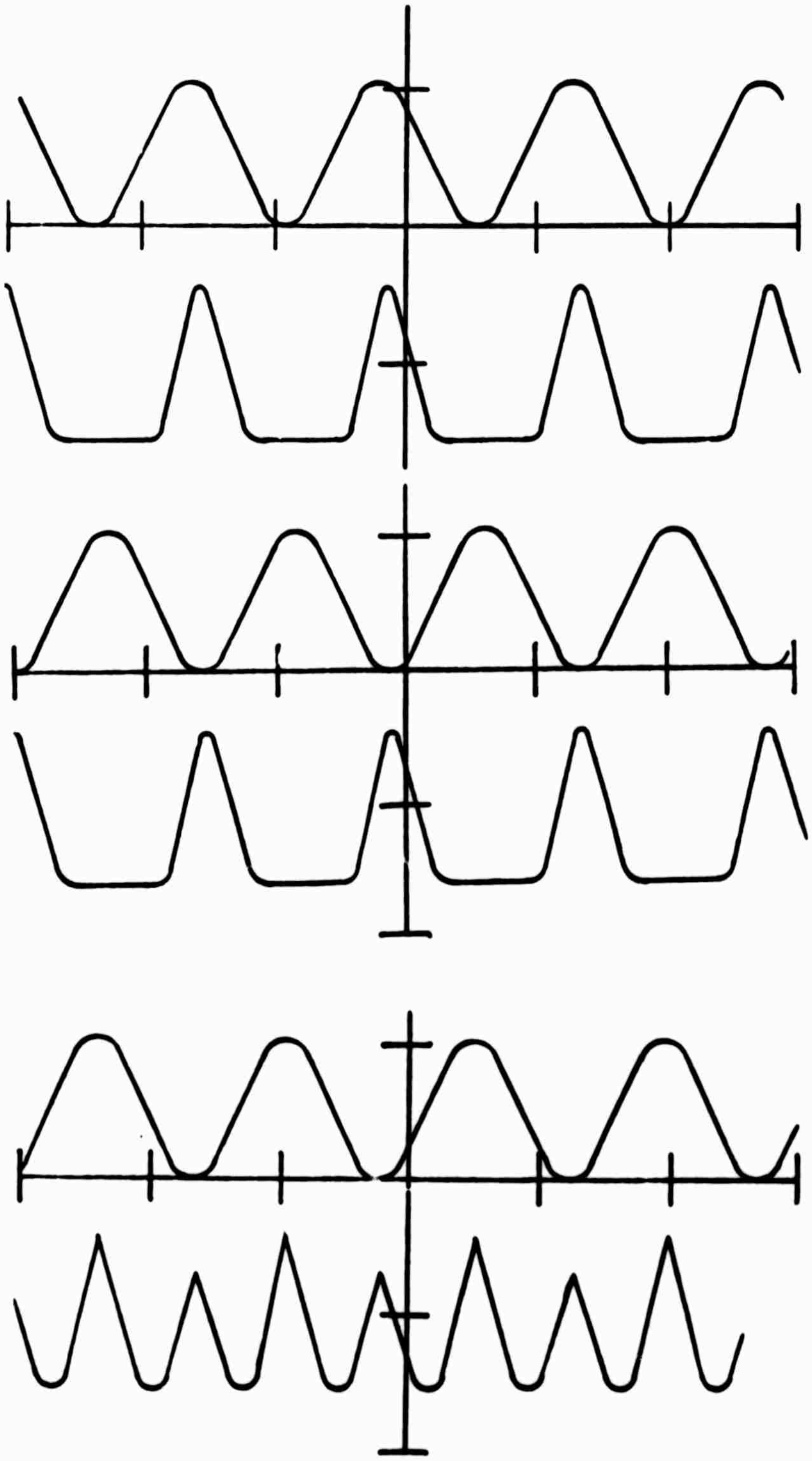

Figure 4 Phase of mode locked pulses relative to modulator drive signal. Modulation frequency equal to the axial mode interval. Upper trace in each frame is the modulator drive signal, and the lower trace is the laser output. Horizontal scale - 90 degrees/div.

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14. KEY WORDS	LINK A ROLE	LINK A WT	LINK B ROLE	LINK B WT	LINK C ROLE	LINK C WT
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Gas Lasers						
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